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A Research on Electricity Generation from Wind Corridors of Pakistan (Two Provinces): A Technical Proposal for Remote Zones

Mazhar H. Baloch [1,2,*], Safdar A. Abro [3], Ghulam Sarwar Kaloi [1], Nayyar H. Mirjat [4], Sohaib Tahir [1], M. Haroon Nadeem [1], Mehr Gul [1,5], Zubair A. Memon [4] and Mahendar Kumar [4]

1 Department of Electrical Engineering, Shanghai Jiao Tong University, Shanghai 200240, China; ghulamsarwar@sjtu.edu.pk (G.S.K.); sohaibtahir@sjtu.edu.cn (S.T.); haroon.nadeem1@sjtu.edu.cn (M.H.N.); mehr.gul@sjtu.edu.cn (M.G.)

2 Department of Electrical Engineering, Mehran UET SZAB Khp Mir's Campus, Khairpur 66020, Pakistan

3 Department of Electrical Engineering, Sukkur IBA University, Sukkur 65200, Pakistan; safdarali@gmail.com

4 Department of Electrical Engineering, Mehran University of Engineering & Technology, Jamshoro 76090, Pakistan; nhmirjat@gmail.com (N.H.M.); Zubair.memon@faculty.muet.edu.pk (Z.A.M.); mahendarkumar@gmail.com (M.K)

5 Department of Electrical Engineering, The Balochistan University of Information Technology, Engineering and Management Sciences (BUITEMS), Quetta 87300, Pakistan

* Correspondence: mazharhussain@muetkhp.edu.pk

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Abstract: The non-renewable energy resources are limited and depleting gradually. As such, energy security has attained the greatest amount of attention globally than ever before. In the meantime, energy crises are already affecting the developing countries such as Pakistan, even though one-third of the population of the country is not even not connected to the national electricity grid. The population with access to on-grid electricity is enduring load shedding of more than 12 h a day. This situation is alarming and require immediate attention is required so as to add alternative energy resources to the country, which has long been relying on imported fuels. It is, therefore, high time that the abundant potential in the renewable energy resources of Pakistan such as solar, wind, and biomass are harnessed. These renewable energy resources are economical and environmentally friendly, and thus considered as sustainable, and the utilization of these in meeting energy demands can help to conserve conventional resources early diminishing. This paper provides a detailed description of the energy consumption and load-shedding scenario in Pakistan thereby focusing specifically Sindh and Baluchistan provinces. Since, wind energy is considered one of the cost-effective renewable resources, six potential sites in these two provinces are considered in this study. These sites lie within 250 km of the southeastern and 800 km of the southwestern regions of Pakistan. One-year wind speed data have been reported for variable heights of these proposed sites which represent to have an annual average wind speed of 6.63 m/s and 5.33 m/s respectively. The power generation data for these location of two provinces is 7.653 GWh, and 5.456 GWh per annum respectively. This study also elaborates on the advantages and disadvantages of harvesting and installing the wind energy and provides a technical proposal for the generation of electricity from the wind in the selected remote zones which are off the national grid. The findings of this paper will help concerned government departments to devise appropriate policies and attract investment in the wind energy sector to eradicate the on-going electricity crisis.

Keywords: wind energy; kWh generation; the Sindh/Baluchistan wind corridor; matrix converter; high voltage direct current (HVDC)

1. Introduction

Energy, mainly in the form of electricity plays a significant role in the socio-economic growth and social prosperity of any country. The world is heavily dependent on non-renewable resources for meeting its energy demand. However, these resources are expected to deplete shortly provided that there is no any other major discovery. As such, if the on-going pattern of energy consumption is not changed, energy scarcity will become evident. It is, therefore, high time to choose sustainable power generation, alternatives for overcoming current electricity shortfalls, and conserving conventional energy resources for future generations. Power generation through renewable energy resources, solar and wind, is the best available option for investment towards meeting the rapidly growing electricity demand [1]. It is also important in the context that global temperature is rising and renewable energy resources are well known to be environmentally friendly. The fossil fuel age for North America, Europe, and Pacific Asia is estimated to be 10, 57 and 40 years, respectively. Therefore, it is necessary to minimize the dependence on fossil fuels for a sustainable future. This study, focusing on Pakistan's electricity crisis, provides a pathway for the utilization of alternative energy resources, in particular, wind energy, for overcoming this electricity crisis and thus helping to raise the national per capita economic index [2].

Compared to other developing countries, Pakistan is facing a serious electricity shortfall. The majority of the rural areas of the country have no access to electricity and even the urban centers connected to the national grid are facing long hours of load shedding [3]. As such, at the moment even massive consumption of indigenous and imported non-renewable resources now seems to be inadequate for meeting the energy requirements of the country. However, these deficits in conventional resources can be compensated by harnessing abundantly available renewable resources such as the wind, solar and biomass energy. Amongst these renewable energy alternatives, the wind energy scenario is the most attractive and thus, in the southern wind corridor of Pakistan, which is comprised of appropriate sites for exploring wind behavior and wind power generation potential, is the focus of study. This part of the country is comprised of approximately 1100 km of coastal area which has the effective potential of wind power generation. As per the geographic survey, Pakistan is located at latitude 24′37″ in North and longitude 62′75″ in East. The landscape area covers an area of 803,950 km^2 (approx.) which include four provinces, Sindh, Baluchistan, Punjab, and Khyber Pakhtun Khawa (KPK) alongside special zones of Gilgit-Baltistan and tribal areas in FATA and FANA. The greatest mountain ranges of Karakorum, Himalaya, and Hindukush, including the northern uplands of KPK and the northern tribal areas are also located in Pakistan. The Baluchistan province, along with the mountain ranges, is the largest deserted/barren land area. The Punjab province is almostly flat, five of the country's most important rivers flow through it [4]. The Thar Desert and the Ran of Kutch is present in the east and west part of the Kirther range within the Sindh province of Pakistan. Sindh and Baluchistan provinces both have the largest wind corridors, which inspired us to choose these two provinces to carry out this study. The six energy zones identified in these provinces are Chuhar Jamali, Jamshoro, Thano Bola Khan, Kati Bandar, Hyderabad, Noori Abad, Gwadar and, Hubchoki. In this study, Aghore, Jiwani, Gadani, and Winder are considered for analyzing the wind potential for the power generation and for the installation of the wind turbines.

The following sections of this article provide a review of the energy outlook of Pakistan and compare its renewable energy expenditures with worldwide investments in green energy. Further, appropriate sites for wind turbine installation in Southern Pakistan are proposed, and a detailed theoretical study regarding wind potential, wind speed deviations, and wind speed density models is developed. Finally, measures for extending the transmission system to remote zones using HVDC and wind model integration with the national central power network is also discussed.

2. Energy Outlooks

The provision of sufficient, secure, reliable, efficient and sustainable energy is indispensable for any nation's development. The enormous demand for energy dramatically increases the energy cost of meeting that demand since most of these resources are imported at expensive rates. However, a reduction in conventional energy resources utilisation and preference for eco-friendly renewable energy resources can lower the cost of energy. There are a number of studies in the literature that are support the idea that harnessing of renewable energy has a great potential in terms of meeting the ever increasing demand. It is estimated that alternative energy resources contribute to around 22% of the total energy consumed. Maximum the harnessing and utilizing of renewable energy resources, lesser would decrease greenhouse emissions and reduce the supply–demand gap and sustainability [5]. Research conducted in various countries such as Slovenia, Ghana, India, Bangladesh, Nigeria, Nepal, and Malaysia [6–13] has concluded that the renewable energy resources are the most favorable and reliable resources for addressing current energy crises like situations in these developing countries. Wind energy is considered as the most valuable primary energy resource among other renewable resources.

The power generation capacity of Pakistan is almost entirely dependent on crude oil, coal, liquefied gasoline and natural gas. Out of a total 85% of per capita power generation from coal, nuclear and hydro contribute 4.5%, 1.1% and 9.2%, respectively [1,14–16]. At the time of Pakistan's inception in 1947, the total power generation of the country was around 60 MW with a population of 31.5 million; the electricity consumption stood at 4.5 units per consumer. This suggests that the supply–demand gap has existed since then. Over the years, rapid modernization in the social life towards current the technical and economic structures improved regarding the levels of consumer's power of electricity consumption. By the end of the 1970s, the power production capacity reached around 1.3 GW; later, in the 1980s, the power network rose up to 3 GW due to the installation and generation of power from various available conventional resources. Ten years later the power production capacity further increased to 7 GW and in 1990 the Ministry of Water and Power issued licenses to the Karachi Electric Supply Company (KESC) Limited for the official generation, transmission and distribution of power keeping in view the rapid growth of power consumer in Karachi city. In 1998, the power sector of the country once again underwent a restructuring that ended up with the foundation of the Pakistan Electric Power Company Ltd. (PEPCO). PEPCO is responsible for thermal power generation, National Transmission and Despatch Company (NTDC) for the transmission of electric power, and Distribution Companies (DISCOs) for the distribution of electricity. The Water and Power Development Authority (WAPDA) since then has been overlooking the hydel resources development and hydropower generation. Following 1994 and subsequent power policies, various Independent Power Producers (IPPs) had also started generating electricity for the national grid. The Pakistan Atomic Energy Commission (PAEC) manages the nuclear power generation. However, despite these developments, Pakistan has been in an energy crisis since 2007, with a power shortage of approximately 5–7 GW. In 2006, ADB reported that approximately 45% of the residential sector is deprived of electricity [17].

2.1. Installed Power Generators

The installed power generation capacity, for the period 2013–2015 is shown in Figure 1. It is evident from the figure that the consumption of oil and gas resources to generate electricity by the thermal power plant is very high compared to other fuels. Moreover, the abundantly available resources such as the wind and solar energy until this period were not considered for harvesting and exploiting them for the power generation [18,19]. However, recently, Zorlu Energy Limited located near Jamshoro, have installed a 50 MW (approximately) wind power plant as shown in Figure 2, and a 100 MW solar plant in Punjab province, as shown in Figure 3, has been commissioned.

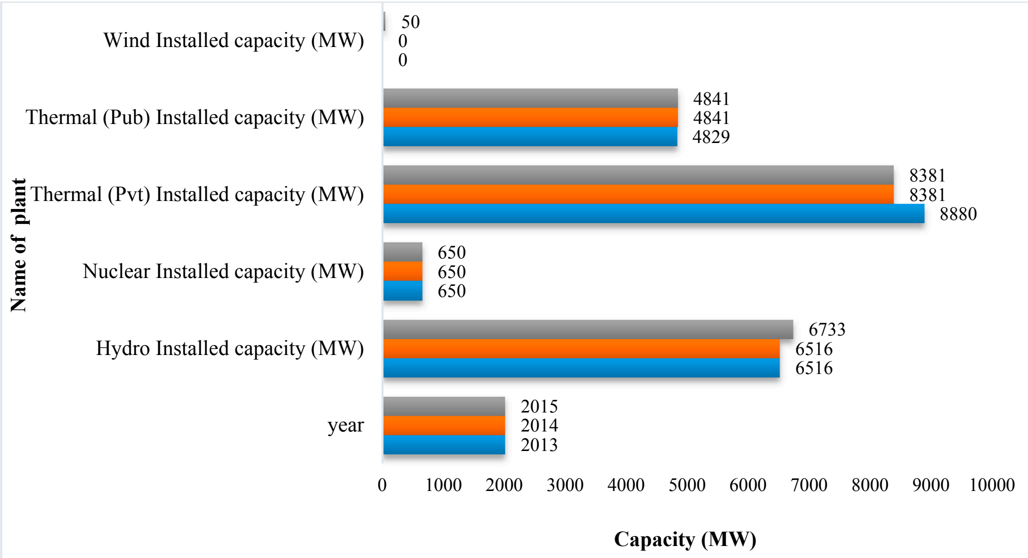


Figure 1. Installed power sectors.

Figure 2. The first 50 MW wind power plant.

Figure 3. The first 100 MW solar power plant.

2.2. Sector Wise Power Generation

Figure 4 shows the GW capacity of power generation utilizing different resources for the years 2012, 2013, and 2014. At this juncture in time, wind power generation has a negligible share in the overall generation of electricity [20].

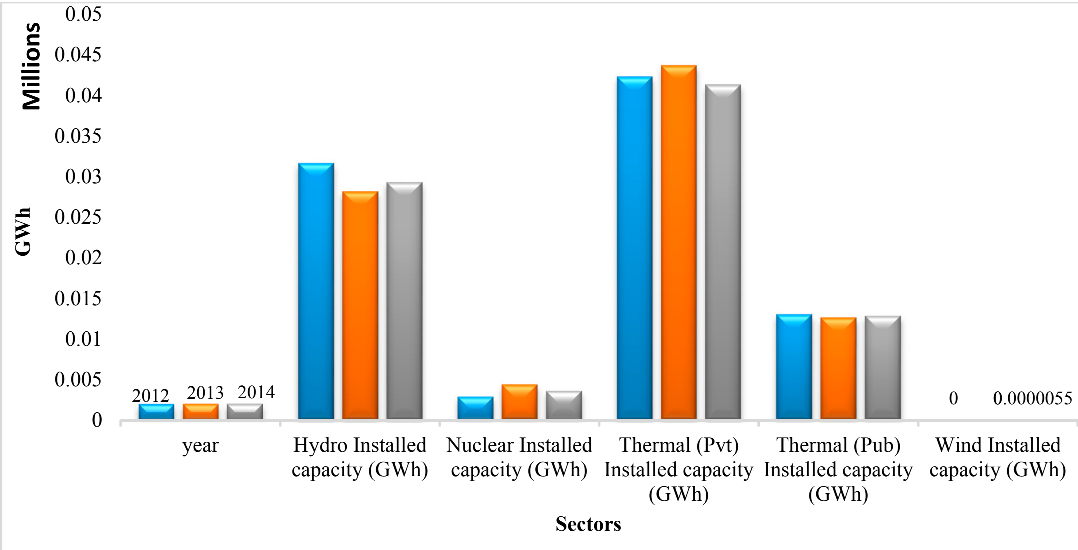


Figure 4. Power generation sector wise.

2.3. Power Electricity Generation, Demand and Deficit Forecasts

Pakistan, currently with neighbouring countries such as China, is currently facing energy supply deficiency issues. It is predicted that failing to tackle this situation will intensify this crises [21]. It can be seen in Figure 5 that, during the period 2012–2015 period, the electricity crisis situation has worsened at a growth rate of 3% per year.

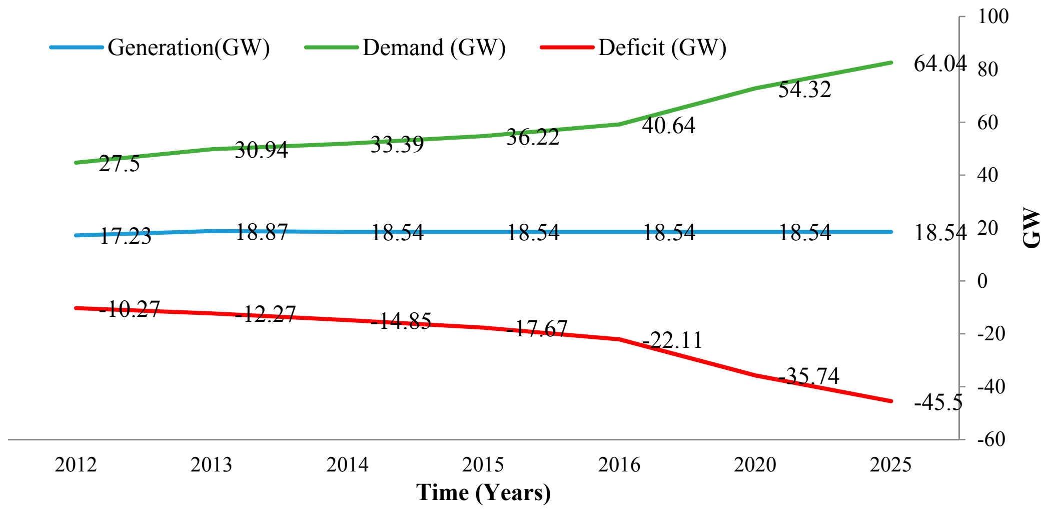


Figure 5. Power generation, demand and deficit by years.

2.4. Sector Wise Energy Consumption

Figure 6 represents the energy consumption in various sectors. As evident from the Figure 6, the energy consumption for the domestic sector, compared to other sectors of the economy, is at a maximum. Meanwhile, the commercial sector shows the minimum energy consumption [11,17].

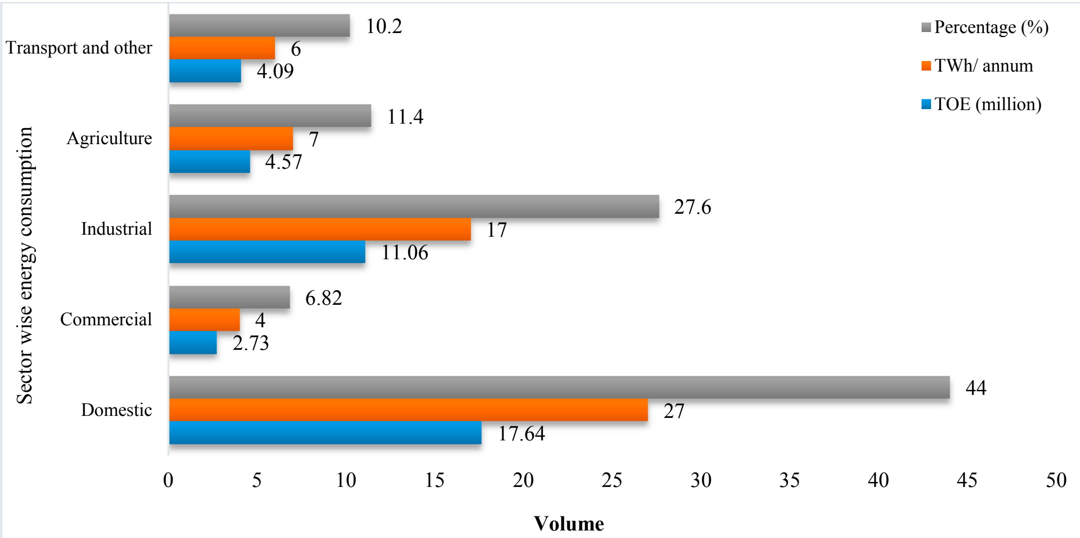


Figure 6. Energy consumption sector wise from 2012 to 2014 (TOE: Ton of oil equivalent, TWh: terawatt hour(s)).

2.5. Wind Energy Outlooks

It is acknowledged by the United States Department of Energy and National Renewable Energy Laboratory (NREL) that Pakistan has an approximately 346 GW potential as shown in Figure 7 [22]. However, this generation potential was estimated to be around 0.5 TW by the end of 2016. The wind speed in the coastal wind zones of Sindh Province is approximately 5–12 m/s [22]. As such, these coastal zones have some abundant resources for wind energy that are estimated to be about 20 GW, which suggests that this province has enormous potential for wind energy, which, upon harnessing, could help in eradicating the electricity crisis [23]. Additionally, the utilization of these renewable energy resources will lead to various job openings, prosperity and community development in the province.

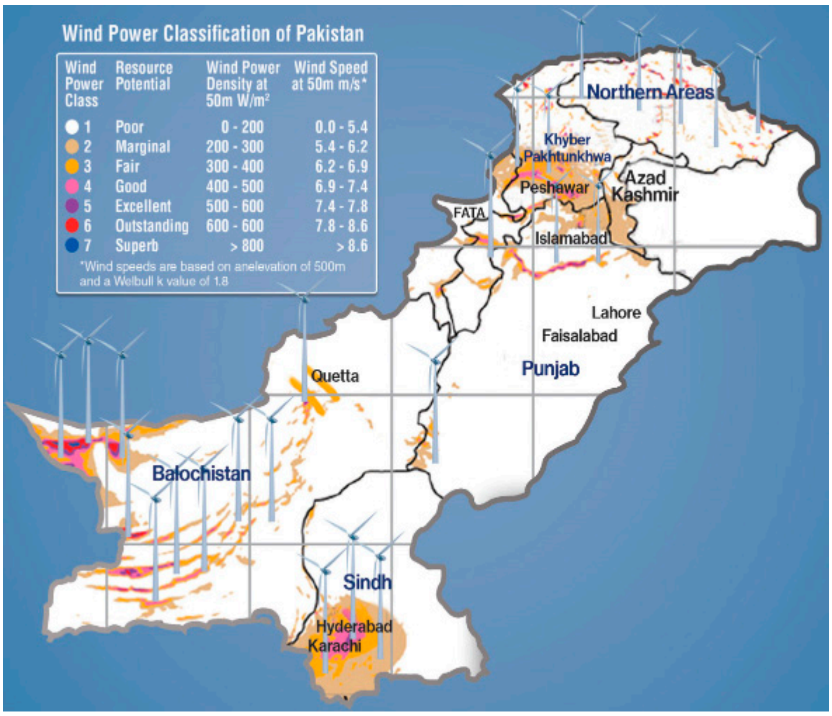


Figure 7. National renewable energy laboratory survey report [22,23].

2.6. Energy Strategy Outlooks

There are multiple efforts underway by the Government of Pakistan to eradicate the ongoing electricity crisis. However, these efforts owing to unclear goals and diversified strategies with reliance on imported fuel, short term planning, and, more importantly, poor governance, have not met the expectation of the power consumers. Some of these initiatives pertaining to the construction of mega dams appear positive but yet at the cost of compromising investments in indigenous renewable energy projects, which can be completed on fast track basis compared to slow paced dam projects. For example, wind energy based micro-grids can offset the electricity demand of domestic and other users (based on various reports detailing the cost of wind energy power generation compared with other power generation sources) [24,25]. In this context, it is also important to reference the various reports of international agencies and financing institutions such as ADB, World Bank and NREL which have been supportive of investments in renewable energy based power projects. Although, the government has set various targets for the addition of renewable power to the grid, this has not been achieved over the years. It was ensured in the national renewable energy policy of 2012 that a 3% share of renewable energy should be ensured in the overall energy mix, in the following years. As such, 2% of the annual development budget was allocated to the development of Alternate Energy Technologies (AETs) and to connecting the AETs based power to the national grid. In consonance with these efforts, Government of Sindh (GoS) have also undertaken various renewable energy projects that are now in different stages of development, some of which have been completed.

Various wind energy development projects of Sindh province are shown in Table A3 (see Appendix A).

3. Global Investment in Green Energy

There is a growing trend globally to utilize renewable energy resources that are generally emission-free instead replace the fossil-fuel-based conventional resources. This change in thought has a certain logical basis. On the one hand, the conventional energy resources are diminishing and causing global warming, but on the other hand, the market prices of these resources are volatile. Pakistan has also taken the initiative in this context: a 0.1 GW solar photovoltaic project in the district of Bahawalpur in Punjab was undertaken in 2015 [26]. In 2011, various countries spent their highest revenues on the development of renewable energy resources [27]. The global investment in renewable energy development for 2004–2014 periods is shown in Figure 8.

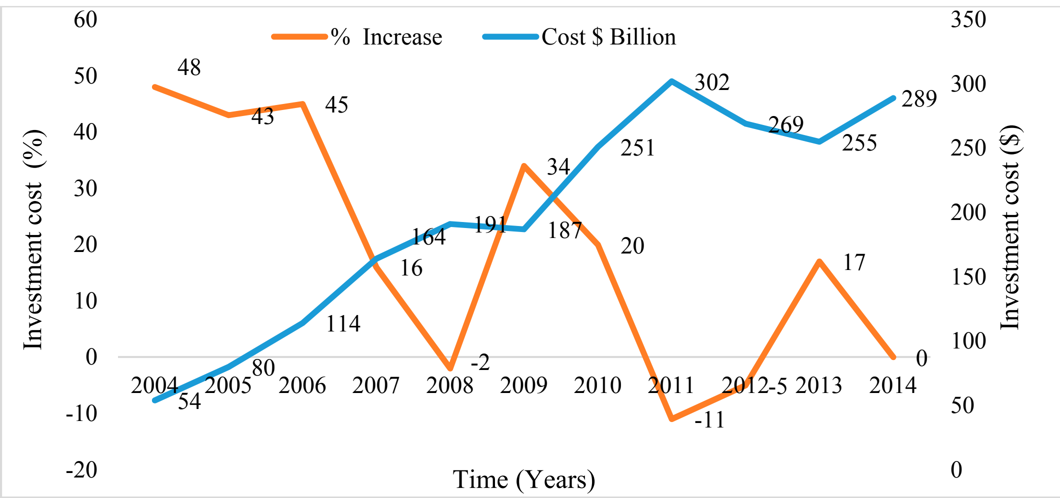


Figure 8. Global investment in green energy.

In the meantime, it is noted that prompt increases in electricity demand have caused a rise in the power costs and an effort to minimise the pollution caused by conventional resources. This has in fact inspired many to explore sources of green energy. In this context, wind energy, compare with other renewable resources, is leading as an indispensable form of electricity production. Considering it is pollution-free, inexpensive, and endless, it is becoming widely popular in both developed and developing countries [28,29]. Many scientists, engineers, and researchers are engaged in exploring an optimal solution for the effective utilization of the renewable energy resources [30–32].

The above mentioned initiatives are essential for harnessing the renewable energy resources as the energy crises are occurring globally. As a result of this initiative the worldwide installed wind energy capacity has enhanced from 1997 to 2014, as shown in Figure 9. Further, Figure 10 shows the wind installation capacity in different continents, and the installed capacity of the top five countries with wind power is shown in Figure 11 [33]. As shown in the literature, in the Asian continent, China is leading, with an aggregate set-up size approximately 0.142 TW and 0.115 TW in the F.Y 2014 [33].

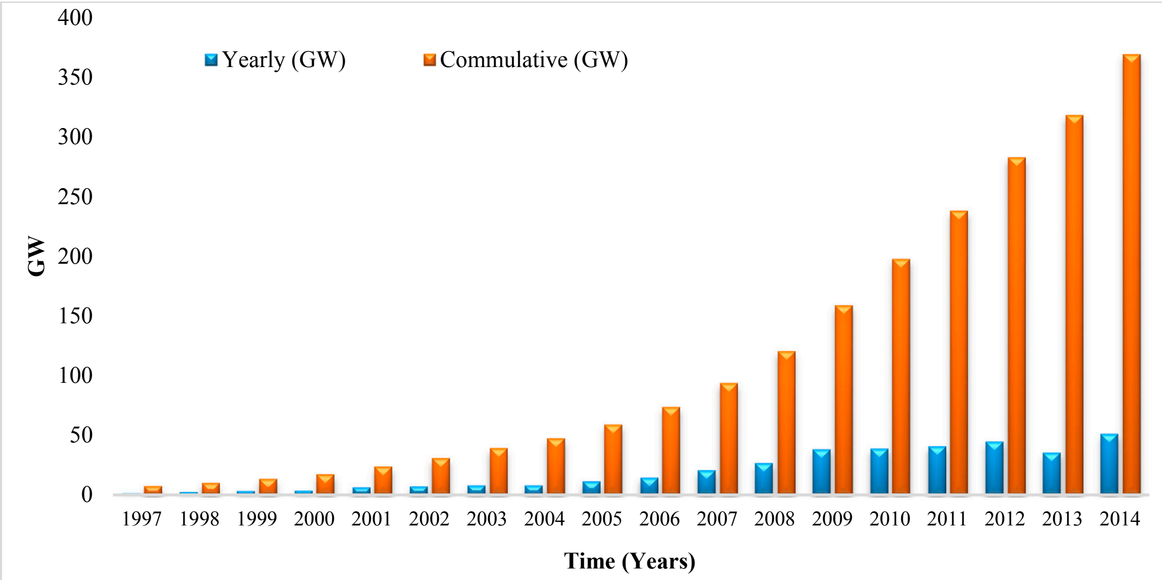


Figure 9. The overall installed potential wind capacity of the world since F.Y 1997 to 2014.

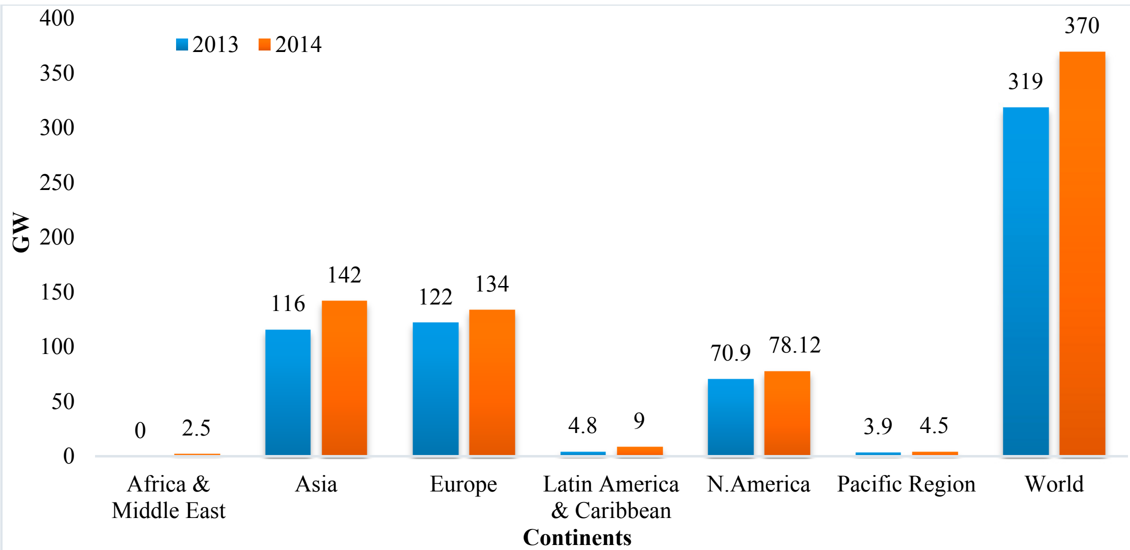


Figure 10. Continents and wind energy power for 2013 and 2014.

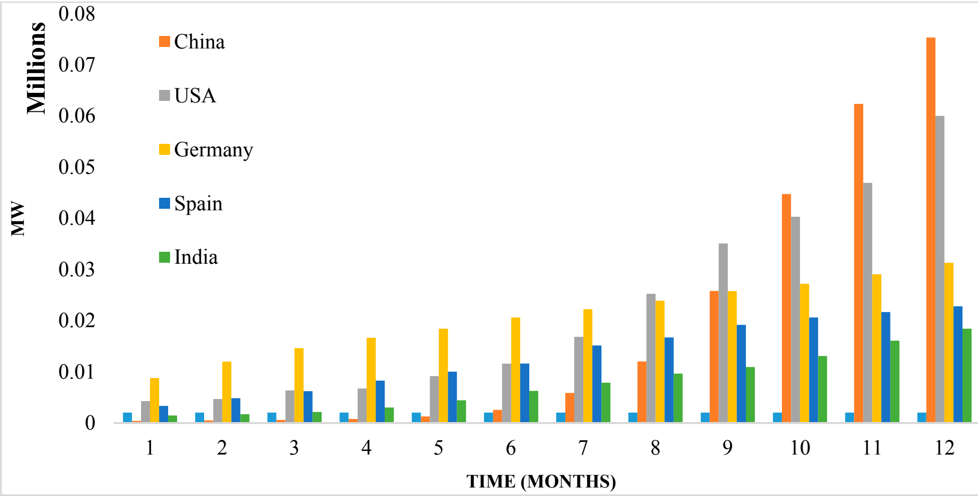


Figure 11. Wind power scenario in five countries.

4. Proposed Sites for Wind Turbine Installation

As regarding Pakistan, according to the surveys, the total area of the country is approx. 796,095 km^2, including the water region whereas the land area is about 77,085 km^2. The coastal line area of Pakistan is almost 1100 km. However, wind zones are mainly in an area of 250 km in Sindh and Baluchistan, which having 800 km of coastal area. This paper mainly considers mainly six coastal zones in the southeastern and easteastern part of the Pakistan. The selected wind corridors of Sindh Province are Hyderabad, Jamshoro, Kati-Bandar, Noori Abad, Chuhar Jamali and Thano Bola Khan, and Gadani, Jiwani, Hubchoki, Aghore, Winder, and Gawader fall within Baluchistan Province (see Figure 12). The data for these selected zones is taken from Pakistan Metrological Department (PMD). According to the international standards, a few points that should be kept in mind when selecting a suitable zone for installing wind towers are as follows:

- ❖ The wind tower should be kept far away from the local barrier to the wind,
- ❖ The selected area should be in the greater part of the zone regarding wind energy.

The wind velocity data of the selected zones was scrutinized and authenticated uninterruptedly on at least an hourly basis for different heights such as 10 m, 30 m and 50 m, as shown in Table 1, with an anemometer for all locations [34].

Table 1. Detail features of the proposed zones for which the wind velocity figures were investigated.

Proposed Sindh Province Wind Zones						
Name of Zone	**Hyderabad**	**Jamshoro**	**Kati-Bandr**	**Noori Abad**	**Chuhar Jamali**	**Thano Bola Khan**
Longitude Latitude	68.367 E 25.367 N	68.263 E 25.433 N	67.276 E 24.941 N	68.525 E 25.894 N	68.112 E 24.349 N	67.462 N 25.243 E
Proposed Balochistan Province Wind Zones						
Name of Zone	**Gwadar**	**Hubchoki**	**Aghore**	**Jiwani**	**Gadani**	**Winder**
Longitude Latitude	62.322498 E 25.126389 N	66.9129 E 25.0529 N	62.355876 E 25.137273 N	61.745876 E 25.047273 N	66.727802 E 25.116345 N	66.668256 E 25.385636 N

Figure 12. Proposed sites map of Sindh and Baluchistan Province [34].

5. Theoretically Studies

5.1. Wind Potential Model

The consequential dual wind speeds, for the assessment of maximum wind energy potential, were obtained from [35–37]. As such, the wind potential model can be described as:

$$\widetilde{V}_{\omega}\frac{1}{C} = \frac{1}{\left(\frac{k'}{k'+2}\right)^{1/2}} \quad (1)$$

where $\widetilde{V}_{\omega}$ is the maximum wind energy, k' & C is the dimensionless factor and C is the Weibull factor.

5.2. Average Wind Speed Deviation Model

At most of the locations, the wind speed changes with an altitude which primarily depends upon terrain roughness and mixing of the atmosphere [38,39].

The wind speed deviation can be described as:

$$\left(\frac{\widetilde{V}_{avg_2}}{\widetilde{V}_{avg_1}}\right) = \left(\frac{h'_2}{h'_1}\right)^{n} \quad (2)$$

where $\widetilde{V}_{avg_2}$ & $\widetilde{V}_{avg_1}$ are the average wind speeds at an altitude h'_2 & h'_1, and the exponent power n is the land surface roughness atmosphere stability. The maximum and minimum limits of n are $1/2$ and $1/20$ [40]:

5.3. Wind Power Density Model

The wind power density estimates the output side of the wind turbine through a suitable base region which is described as follows [18–41]:

$$P_{wind} = 0.5\rho\pi R^2 {V_{\omega}}^3 \text{ and } P_{wind} = P_t(C_p\omega_t)^{-1}C_p = 0.73\left(\frac{151}{\lambda_c} - \frac{132}{100}\right)\exp\left(18.4\frac{1}{\lambda_c}\right)^{-1} \quad (3)$$

where ρ is the air density (kg/m^3), R is the turbine blade length (m), ω_t is the turbine speed (radian/s), P_t is the turbine power, and C_p is the power coefficient. It is well-known for simulation purposes that the aerodynamic rotor turbine efficiency is expressed according to the Betz law. The theoretical and practical limits of C_p are from $1/5$ to $2/5$ and from $2/10$ to $4/10$ [18–41], respectively. Moreover, in Equation (3), λ_c is the tip speed ratio and characterised as follows, considering the pitch angle at zero degrees, is characterized as follows [18–41]:

$$\lambda_c = \left(\frac{1}{\lambda - 0.002\delta} - \frac{0.003}{\delta^3 + 1}\right)^{-1} \tag{4}$$

The monthly/yearly power density defined as the ratio of wind power density per unit area of a turbine at a specific wind zone and expressed as follows [42,43]:

$$\text{Power}_{\text{Density}} = \frac{\text{P}_{\text{avg.wT}}}{\pi \text{R}^2} \tag{5}$$

where $\text{P}_{\text{avg.wT}}$ is the average wind turbine power.

The average output wind power is a key factor compared with the rated power. This calculates the output energy from a period that influences the cost-effective probability of a wind power generation scheme. However, various wind machines show different behaviours for the output power curves (see [27,44–47]). Equation (6) is used for simulation purposes with the mechanical turbine.

$$\text{P}_{\text{electrical}} = \begin{cases} 0 & \langle V_{cut\,in} > V_\omega \rangle \\ \text{P}_{\text{rated}} \frac{V^{k'}{}_{cut\,in} - V^{k'}{}_{\omega}}{V^{k'}{}_{rated} - V^{k'}{}_{cut\,in}} & \langle V_{rated} \geq V_\omega \geq V_{cut\,in} \rangle \\ \text{P}_{\text{rated}} & \left\langle V_f \geq V_\omega \geq V_{rated} \right\rangle \\ 0 & \left\langle V_\omega > V_f \right\rangle \end{cases} \tag{6}$$

where

$$\text{Power}_{\text{avg: electrical}} = \text{P}_{\text{rated}} \left\langle \frac{e^{-\left(V_{cut\,in}/C\right)^{k'}} - e^{-\left(V_{rated}/C\right)^{k'}}}{\left(V_{rated}/C\right)^{k'} - \left(V_{cut\,in}/C\right)^{k'}} - \frac{1}{e^{\left(V_f/C\right)^{k'}}} \right\rangle \tag{7}$$

where $V_{cut\,in}$, V_{rated}, V_f and P_{rated} are the cut-in speed, the rated speed, the cut-off speed, and the rated power, respectively.

The capacity factor (CF) is defined as the ratio of average power rated to the theoretical maximum energy at the output during the specific time span is given as follows:

$$\text{CF} = \frac{\text{Power}_{\text{avg: electrical}}}{\text{Power}_{\text{rated electrical}}} \tag{8}$$

However, the theoretical and practical limits of CF are 100% and 20–70%, respectively, which falls from 20% to 30%. On the other hand, the wind turbine (WT) cost-effectiveness probability not only depends on the capacity factor (CF) as well as on the expenditures of the substitute electrical system. Likewise, a small amount of CF does not mean that the scheme is not suitable for the precise wind regions as mentioned before. The standard deviation described as:

$$\Delta = \left(C^2 \left\{ \Upsilon\left(1 + \frac{2}{k'}\right) - \left[\Upsilon\left(1 + \frac{1}{k'}\right)\right]^2 \right\} \right)^{0.5} \tag{9}$$

where Υ is the gamma function [42,48–57].

5.4. International Standards of Wind Power Classification

According to the international standards, it is necessary to develop simpler wind potential classifications in detail as shown in Table 2. The different classification parameters are wind speed (m/s) and wind power density (watt/m^2) at an altitude of 10, 30 & 50 m of the wind turbine. With the help of Table 1, wind corridor development could be undertaken for the proper installation of larger wind power plant. Moreover, Section 4, considered the future of the developing countries, and the Sections 1 and 2, designed for smaller wind turbine unit [58].

Table 2. International standards of wind power generation classification.

Various HEIGHTS		At 10 m Heights		At 30 m Heights		At 50 m Heights	
#	**Resource Class**	**m/s**	**W/m²**	**m/s**	**W/m²**	**m/s**	**W/m²**
1	Poor	0–4.4	0–100	0–5.1	0–160	0–5.4	0–200
2	Marginal	4.4–5.1	100–150	5.1–5.9	160–240	5.4–6.2	200–300
3	Moderate	5.1–5.6	150–200	5.9–6.5	240–320	6.2–6.9	300–400
4	Good	5.6–6.0	200–250	6.5–7	320–400	6.9–7.4	400–500
5	Excellent	6.0–6.4	250–300	7–7.4	400–480	7.4–7.8	500–600
6	Excellent	6.4–7.0	300–400	7.4–8.2	480–640	7.8–8.6	600–800
7	Excellent	>7.0	>400	8.2–11	640–1600	>8.6	>800

5.5. Comparative Study of Proposed Sites with International Standards of Wind Power

Based on generally accepted rule of thumb (i.e., 1 km^2 = 5 MW), it has been investigated that the proposed sites have enormous potential for power generation as shown in Table 3). Additionally, the windy region percentage is estimated by the land region (excluding water region). However, it is observed that the proposed sites compared with international standards fall from in the 3rd (moderate) to the 7th (excellent) class as shown in Table 3. Table 3 assesses Pakistan's most renowned windy zone potential in arithmetic terms. It is evident from this information that Pakistan has a total of more than 9% of plot area which is most appropriate for convenience scale power plants applications based on wind turbines. The total wind power capacity from the proposed sites is 88.460 GW and 146.145 GW in Sindh and Baluchistan, respectively. It has been documented that approximately 3.5% of the plot, which falls in Class 4 or above would be the main required for cost effective electricity generation from wind source (see in [59]. In fact, this is the clear requirement that Pakistan needs to meet on an urgent basis to effectively exploit this enormous potential that does in fact meet international standards.

Table 3. Proposed sites wind zones assessment for power generation.

Name of Wind Zones		Sindh Province Resource Zones			Baluchistan Province Resource Zones		
#	**Class**	**Total Windy Zones (%)**	**Land (km²)**	**Potential Capacity (GW)**	**Total Windy Zones (%)**	**Land (km²)**	**Potential Capacity (GW)**
3	Moderate	8.76	12,349	61.745	4.75	16,487	82.435
4	Good	3.29	4640	23.2	2.22	7709	38.535
5	Excellent	0.50	703	3.515	0.78	2722	13.610
6	Excellent	0	0	0	0.54	1891	9.455
7	Excellent	0	0	0	0.12	420	2.1
Total		**12.55**	**17,692**	**88.460**	**8.41**	**29,229**	**146.145**

Two provinces total wind zones capacity = 20.96 percent, Land capacity = 146,921 km^2 and Power generation capacity = 234.605 GW.

5.6. Hypothetical Study of Wind Power

In this hypothetical study, wind turbines manufactured by a German company GmbH Bonus 600/44 MK IV type has been considered for power generation. The expected life of such a turbine is around 20 years, which has the highest potential of a 0.6 MW cut-in and cut-off wind velocity of 3 m/s and 25 m/s, for a 50 m hub-height, with a turbine rotor with three blades and 44 m diameters. The analytical wind data have been simulated using MATLAB to estimate the approximate results. As such, only one year of data was used to simulate the monthly and annual capacity factor from the six selected different wind corridors of Sindh and Baluchistan province for the estimation of output electric output power at 50 m wind turbine hub heights.

6. Result and Discussions

In this study, the several factors, of proposed wind power station sites, such as the average monthly and the average annual value of standard deviation, wind power density, the significance of *C* and *k*′ respectively at 10 m, 30 m and 50 m wind turbine heights, respectively, have been considered (see Table A1). However, the greater value of factor C indicates a grater probability of high wind speed. Similarly, higher values of factor k′ indicate that the wind speed is uniform. It is evident from Table A1, that both factors C and k′ take large wind data values from the 4th to the 9th month of the year, which was collected from the selected wind zones of this study.

6.1. Proposed Site 1: Sindh

The following sites are proposed for generating electrical power in MWh units. The capacity factors, which play an important role during the installation of wind turbines, are represented in percentage, both monthly or annually for 50 m heights only (please refer to Table A2 for detailed analysis at 10 m and 30 m heights). The MWh generation and capacity factor determined are shown in Figures 13 and 14, respectively. It is concluded that, for Proposed Site 1, in the selected wind zones, approximately 7.653 GWh units can be generated annually, which can substantially help to reduce the supply-demand gap.

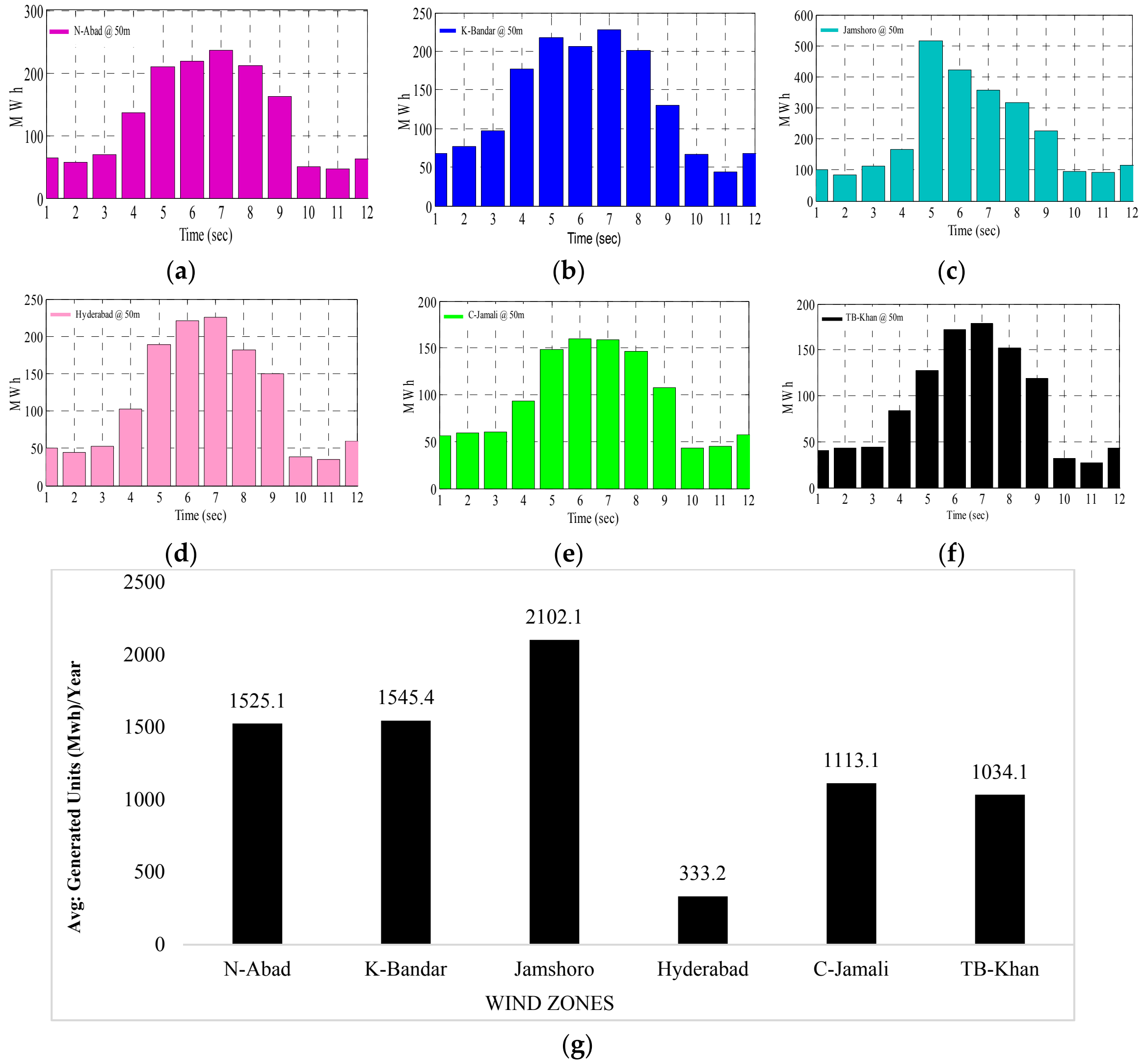
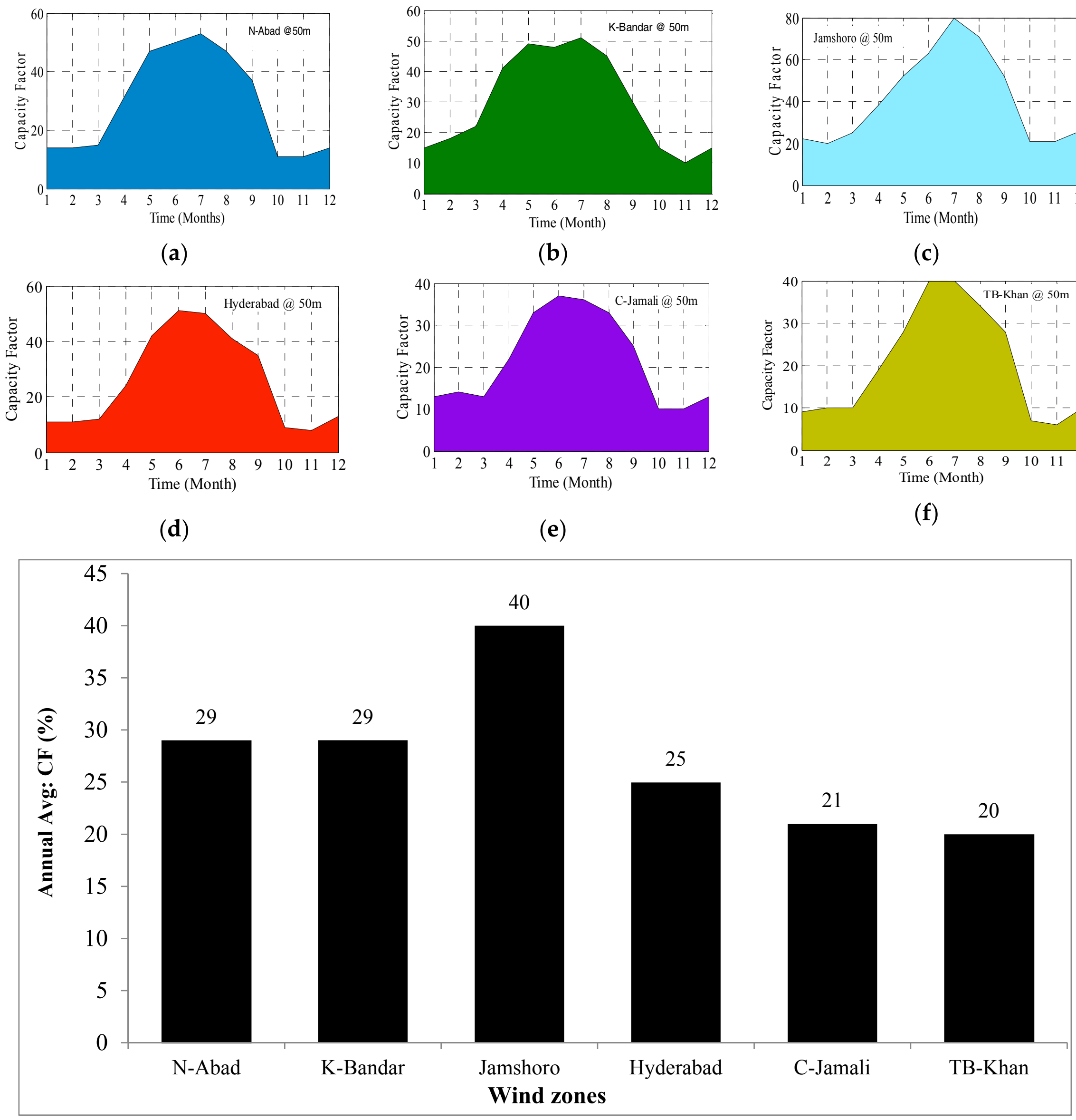


Figure 13. (**a**–**f**) Monthly and (**g**) annual average MWh generation from different wind zones (Sindh province).



(**g**)

Figure 14. From (**a**–**f**) shows monthly and (**g**) annual average capacity factor from different wind zones (Sindh province).

6.2. Proposed Sites 2: Baluchistan

Similarly, two sites in Baluchistan are proposed for generating electrical power in MWh, and capacity factors are requested in percentages on a monthly and annual basis at 50 m heights only (Please see Table A2 for a detailed analysis at 10 m and 30 m heights), as is visualized in Figures 15 and 16, respectively. It is concluded from the analysis that, for the selected wind zones, an electricity generation of 5.456 GWh units is estimated. The annual capacity factor for the two sites of the Baluchistan is approximately 104%. Finally, it is concluded that the monthly power generations for the selected wind zones is workable and may be implemented for the rest of the wind zones of the. Figure 15 shows the wind power generation pattern for the two sites of Baluchistan province with the maximum power generation noted from March to September.

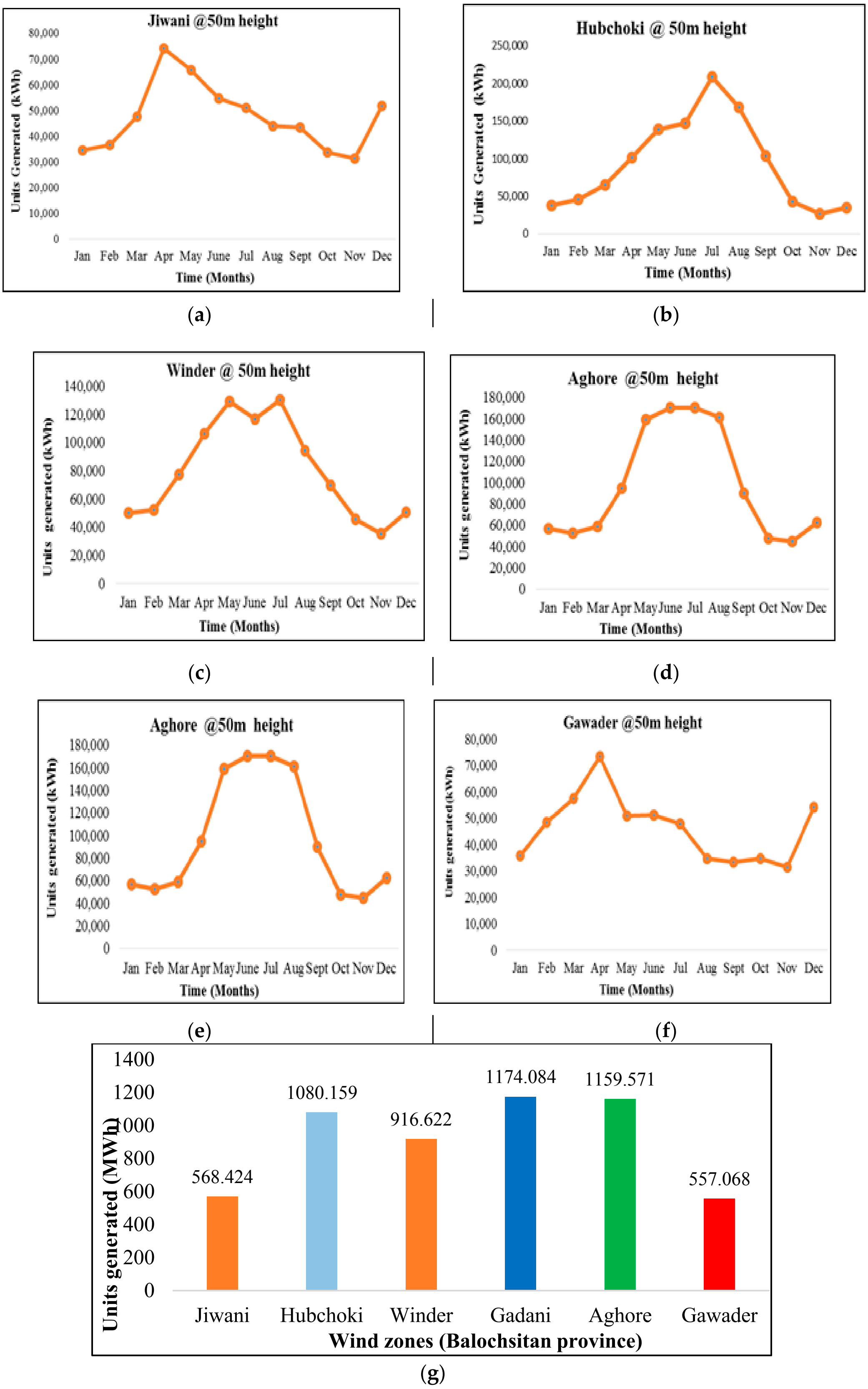


Figure 15. (**a**–**f**) Monthly (kWh) and (**g**) annual average MWh generation from different wind zones (Balochistan province).

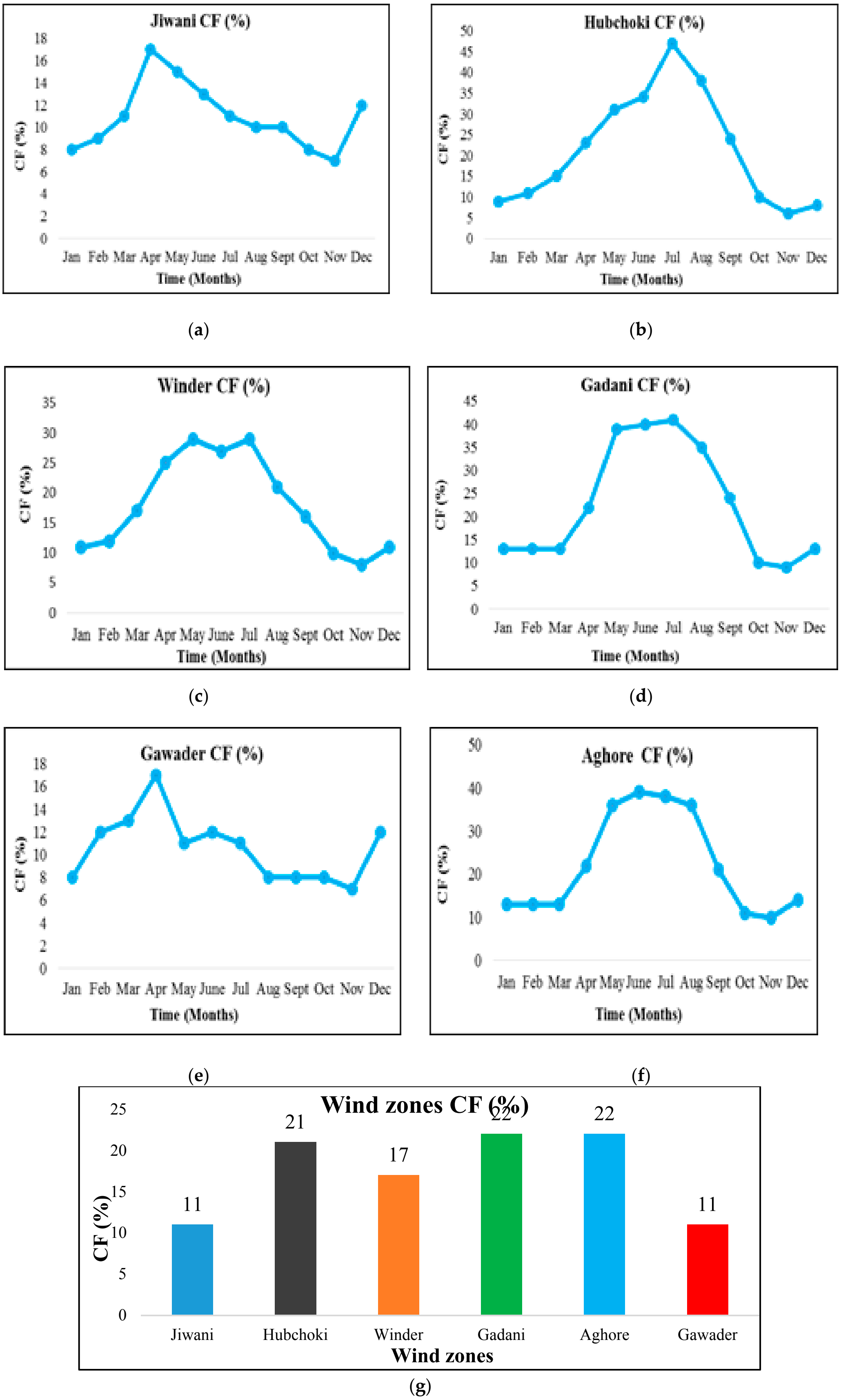


Figure 16. (**a**–**f**) Monthly and (**g**) annual average capacity of different wind zones (Balochistan).

7. Proposing High Voltage Direct Current Transmission System for Remote Zones

The design of wind turbines depends on standard techniques and tools employed for larger scale wind turbine plants. However, small turbines have varying features due to their field of application. This study, however, has considered the economic impacts of the installation of wind turbine systems in remote zones, as proposed in the literature [60]. It may be noted that various sites of wind zone including Proposed Site 2 (Baluchistan), of this study are located far away from the existing power transmission network, therefore, a new power transmission network is required essentially for the dIspatch of generated electricity. The nearest 220 kV grid station is located approximately more than 700 km away and is controlled by the Karachi Electric Supply Company (KESC). In order to reduce the transmission losses, it is proposed that an HVDC transmission line project should be implemented. The HVDC lines provide solid control of both active and reactive power. Furthermore, the WECS and the central power network are asynchronously coupled, as the generators installed at the plant do not play a role in accommodating short circuit currents in the central power network [61]. The greatest benefit of HVDC assembly is a power transfer in bulk by comparatively a reduced number of conductors. The bi-polar structure is relatively preferred, with double self-regulating power poles in the case of HVDC conduction instead of a dual circuit scheme in an AC transmission system.

8. The Proposed Wind Model Integration with a Country Central Power Network

The proposed network design for linking the main grid to the WECS installed in remote zones is shown in Figure 17. For the conversion of the variable frequency (VF) and variable voltage (VV) to a fixed frequency (FF) and fixed voltage (FV), a modulated matrix converter can be installed at the output of each wind turbines. In order to increase the voltage magnitude of the plant at high frequencies, power transformers must be installed. A voltage source converter (VSC) based plant side HVDC connection with a transformer is proposed for converting high frequency AC voltages to high voltage DC at a voltage level of $\pm$300 kV. A bi-polar configuration is used for connecting WECS to the central power network. A huge financial saving can be achieved through high voltage DC by avoiding tapping along the transmission route. A DC-to-AC converter is installed at main grid station for the conversion of HVDC to 220 kV AC voltage at a constant frequency (i.e., 50 Hz). Basically, this type of inverter provides a flat interconnection of wind power plants to the central power network along the countryside. In addition, the harmonic content in output waveforms is improved through voltage source converter (VSC) in the high voltage DC-link, and there is an improvement in the power factor improvement and a reduction in filter size. Moreover, output waveforms can be improved further by installing filters at effective grid stations for reduce harmonics content in output AC waveforms [61]. Finally, it is concluded that the proposed converter is especially appropriate for wind power station in remote zones. With the advances in technology, and the addition of extra loads on the power grid, power demand around the globe is increasing tremendously. However, building an extra transmission line and power substation alone does not serve the purpose of overcoming energy/power shortfall. Thus, a major transformation in the electricity sector is required. Therefore, a few recommendations are needed so as to shift the country's conventional grid system to the smart grid which will also be helpful in terms of installing the wind turbines in the remote zones [62].

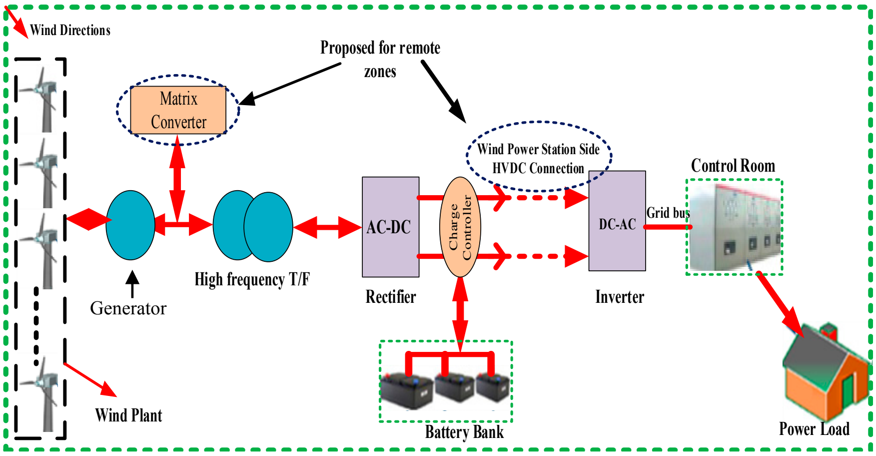


Figure 17. Proposed wind model integration with national power grid.

9. Challenges Faced During Implementing of Wind Turbines

The electricity shortfall of Hyderabad Electric Supply Company (HESCO) and Quetta Electric Supply Company (QESCO) could be minimized by installing the windmill units along the coastal lines of the proposed wind zones. The load shedding of electricity currently ranges between 8 and 12 h in cities and more than 18 h in the villages of these distribution companies [63,64]. Nevertheless, the installation of wind turbines faces certain challenges which are discussed as below.

9.1. Initial Investment

In the year 2009, K.D. Julia et al. [65] found that the initial investment of the installation of a wind turbine unit is very high compared to a conventional power plant. According to a New York Times report published in May 2015, the daily per capita income of the consumer is approximately $4.3, which is continually increasing on a daily basis [66], but is not conducive to the installation individual local wind turbines. Even the government faces hardships in managing the required funds for the development of such a project. The best way out of this situation would be either a public-private partnership or private investments. A competitive and fair process for the award of licenses would encourage investors.

9.2. Suitable Site Selection

A suitable site for the installation of wind power plant is an important aspect. For example, tall building structures are not appropriate due to the turbulence and shear of wind turbine units. Consequently, the output wind energy output is reduced by wind turbulence and shear [67]. The government of Pakistan (GoP), with the help of the Pakistan Metrological Department, has taken a keen interest in searching for suitable sites in the southern region of Sindh and Baluchistan. Such efforts would help in resolving wind power plant site selection.

9.3. Wind Output Power Quality

In the electrical power system, the quality of the power is very important, especially from wind power plants, owing to the uncertain wind speed. The irregular shape of the input in the wind turbine system diminishes the life of electrical machines and increases the losses [68]. Therefore, it is necessary to follow the IEC and other international standards for maintaining power quality while undertaking wind energy projects.

9.4. Low Frequency Noise

P. Nina and P. Jerry et al. [69,70] demonstrated that the low-frequency noise has a negative effect on human health. Such type of noise effects on the human mind and body, therefore, need to be avoided. It is very important that one should strictly follow the international standards are strictly followed. Appropriate research may also help in suggesting a way out in this context by improving the mechanical designing of wind turbines.

9.5. Benefits to the Electric Power Distribution Company (HESCO & QESCO) and Utility Consumers

There are several benefits to the power companies such as HESCO/QESCO, as well as other DISCOs, and individual consumers, form installing large and small wind-turbine units, which are briefly summarised below [71–75]:

- A rise in power production capacity.
- Reducing power losses in transmission lines.
- Reduced CO_2 emission.
- Fresh and pollution restricted air.
- Extra trustworthy power.
- Decrease in electricity tariffs.
- A roadmap to the smart/micro network.

10. Various Incentives for Foreign Companies

The government of Sindh (GoS) has shown great commitment to the developing wind energy projects and have devised various projects for realizing the maximum potential of this resource. The estimated potential of the Sindh province wind corridor is 50 GW around the coastal line with an average monthly wind speed of 8 m/s [76]. According to the renewable energy policy in 2006, GoS provided various incentives to attract the foreign companies to invest in wind energy projects [76]. Such incentives may also need to be announced the government of Balochistan and implemented appropriately to harness the wind energy resources. Key incentives which may be considered for wind energy harnessing projects are as follows:

- The available land for the eligible investors with an annual rent of 102 Pak Rs. (~1 US dollar)/sq. Yard/annum for the directly impacted area.
- A straight tariff rate of 16 Pak Rs. (~13.2 US cents) per electricity unit should be set for all investors, who are willing to complete their given tasks/projects in 1.5 years.
- A 20 years agreements for the power purchaser, i.e., water and power development authority (WAPDA) by GoP through Implementation Agreement & Sovereign Guarantee (IASG).
- A complete wide-range exposure to investors against the risk of change in rules through Force Majeure provisions and political risk.
- 5 years wind speed data is available from several GoP sources such as, PMD, that estimates the accurate performance, direction, density, and power of wind energy output.
- The implementation of complete wide-ranging tariff reles on a cost rated basis.
- Fiscal incentive/motivation through zero income tax, in which the solitary involvement of local exchequer will be given a 7.5% withholding tax on dividends declared across the life of the project.

11. Conclusions and Recommendations

Based on the detailed analysis presented in this paper, the following conclusions can be drawn from this research:

- Monthly and annual average wind speed data from different wind stations are shown in Table A1 Considering WT classification, if the speed of wind of a given location is from 7.2 to 8 m/s and from 8 to 8.8 m/s at 30 m and 50 m hub-heights, respectively, such l location would excellent for the installation of WTs. It has been observed that the most suitable wind zone is the Jamshoro zone where the extreme and slightest speed of wind reaches approximately 13.9 m/s and 5 m/s at 50 m hub-heights.

- Electrical units generated from the six selected wind zones from both proposed sites are enough to overcome the electricity shortfall situation in the country which is around 6 GW.

Therefore a few recommendations for the GoP have been put forward to minimize the electricity crises and enable the supply of electricity to rural areas.

- On an urgent basis, the GoP must focus on national energy strategy projects that are low cost and requires minimum completion time to tackle the electricity crisis issues and furnish the required power of the country.
- Conventional power plants are too old and have a power generation efficiency of 15%; thus, they should be maintained, and possible retrofits should be provided to enhance the power yield and to prevent technical and non-technical losses.
- Governing body systems of power companies (GENCO'S, NTDC, DISCOs) should be improved.
- Power theft and other non-technical losses on the electricity distribution side must be reduced.
- The GoS should coordinate with the GoP and related institutions to implement small home based windmill units in windy zones, especially in rural areas.
- 20% to 30% of losses are observed owing to the old and inefficient substructure of the power-grid, power-plants, and transmission/distribution lines, were observed. Following the global standards, these losses should be minimized.
- The GoP, should motivate and provide suitable incentives to foreign companies/investors to focus on time-based completion of, for example, wind and solar projects.
- The GoP should introduce research and development funds for alternative energy projects so that top-ranking national institutions and organisations can determine the best option in terms of introducing and disseminating the exploitation of alternative resources.

Finally, it is concluded with respect to outcomes that the selected zones of Sindh province with massive wind capacity should be considered for wind power generation plants. Therefore, it is urgent that the GoS and the GoP utilise these golden wind zones on an urgent basis by keeping per unit generation cost, as compared to the cost of conventional resources, at a minimum.

12. Future Research Directions

The following points are recognized and suggested for the researchers, scientists, and engineers especially from Sindh province working in the field of alternative/renewable energy.

- Important future developments in the research must require an effective strategy of evaluating the accuracy of wind energy generation systems.
- Significant methods should be developed for predicting the wind speed.
- Various up-to-date algorithms for software based probabilistic interpretation is needed for future research objectives.
- More advanced software tools for sculpting, drawing, development, analysis, testing and justification of the abilities and modularity of a wind energy system should be integrated with the power-grid.

It is, therefore, concluded from this research study to further focus on safety, cyber security, minimum cost, feasibility, compliance, and monitoring.

12.1. Proposed Solutions for Future Recommendation

On the basis of ground realities, it can be estimated clearly that obliteration of ongoing energy crisis in Pakistan is extremely difficult by short term measures. However, these crises can be overcome for a temporary span of time by instigating and implementing measures suggested in this paper, which are summarized as follows.

12.1.1. Short-Term Solutions

To overcome the ongoing power crisis, the following short-term measures must be implemented immediately:

- On an immediate basis, wind power plants must be installed. Because of their quick installation time and immense capacity in Southern Pakistan, a smooth flow of energy can be assured, and slight increases in the supply-demand gap can be prevented.
- Many power stations in the country are currently non-operational due to because of minor faults. These can be made operational by, with the help of a little investment, refitting and making technical enhancements. The immediate need is to revive these units to save the economy from destruction.
- Apart from the supply side, consumers also need to play their role in exterminating the crisis. In this context, the commercial sector must place limits on commercial centres, i.e., shopping malls, to close at 10 p.m. Energy saved in this way might transmit to other sectors of the economy.
- Power theft is correspondingly a major cause of electricity shortfall and needs immediate measures must be taken for its eradication.
- In agricultural and industrial sectors awareness campaigns should be initiated to adopt innovative and proficient techniques for conserving water and power utilization.

12.1.2. Long Term Solutions

Power consumption is mainly increasing due to the increasing number of domestic consumers and the growth in the industrial sector. As such, the following long term measures should be taken to ensure the continued supply to all other consumer groups as well.

- Pakistan ranks 3rd in the world in terms of coal assets, which are located in the southeastern region of Thar Desert (Sindh). Estimates suggest that that 33.0 trillion tons of coal is available in the Thar Desert. Pakistan's electricity crisis can be overcome by exploiting coal reserves for electricity generation. This can be a long-term solution for electricity generation. This power production is more economical as compared to thermal power production based on other imported fuels. The analysis also depicts that a more 0.2% usage of Thar coal can generate 20 GW of electricity.
- To meet the increasing demand, another long-term measure is to construct more hydroelectric projects and nuclear plants in Pakistan. Several Chinese and Norwegian companies have asked the government to provide technical experts for consultation regarding the construction of dams. Apart from electricity generation, the creation of new water reservoirs would also be beneficial in terms of cutting-edge water storage, alleviating and growing problem of water shortage in the country.
- The foreign policy of the country should be managed according to its economic and energy requirements. As it plays a vital role in long-term planning and goals. The government of Pakistan needs to improve the relations and establish ties with energy-rich countries for technical advancement and financial investment in the power sector.

12.1.3. Renewable Energy Potential Solutions

Short-term and long-term measures for electricity generation should be taken. Apart from this, renewable energy resources should be exploited to provide a possible solution for the eradication of Pakistan's power crisis. Pakistan's indigenous non-conventional resources and their potential have been discussed in detail. However, a brief overview of strategies for overcoming this electricity crisis is described below:

- **Biogas:** Pakistan is primarily an agronomic state with adequate livestock. Therefore, the country has the prodigious potential for energy production from biogas. The assessed possibility of power generation by biogas is nearly 8.8 to 17.2 billion m^3 (almost equals 55–106 TWh of energy, for meeting Pakistan's existing overall power necessities). This demonstrates that approximately 5700 GWh, i.e., 6.6% of Pakistan existing power generation of electricity could be generated through biogas.

- **Wind potential:** Total potential for wind power generation is above 300,000 MW. To increase the generation of electricity and for meeting the demand, wind energy potential can be effectively exploited.
- **Hydropower potential:** The hydro power potential of Pakistan, documented until July 2016, is approximately 51,700 MW which is comprised of large hydropower sources.
- **Solar Photo Voltaic potential:** Pakistan is blessed with efficient insolation. Average solar radiation in Pakistan is 5 to 7 kWh per m^2 per day; this solar irradiation is one of the best figures in the world in terms of solar power generation. Pakistan can produce over a million MW of photovoltaic (solar PV) electricity via integration with the country's national grid of Pakistan, provided that there is suitable space for solar panel installation.

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Author Contributions: Hussain had for the initial study purpose. Abro, Haroon, Mehrgul, Sohaib and Sarwar were the responsible for the wind study data collection from various wind zones of Pakistan. Hussain, Zubair, and Mahendar set the analysis technique framework for compilation the data in terms of results. However, all mentioned authors wrote the manuscript and Nayyar correct the paper regarding grammatically.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

kWh	Kilo watt hour
MWh	Megawatt hour
GWh	Gigawatt hour
HVDC	High voltage direct current
HVAC	High voltage alternating current
WECS	Wind energy conversion system
km	Kilo meter
GW	Gega watt
KESC	Karachi electric supply company
PEPCO	Pakistan electric power company
WAPDA	Water and power development company
NTDC	National transmission and dispatch company
IPPs	Independent power producers
GENCOS	Generation companies
DISCOS	Distribution companies
KANUPP	Karachi nuclear power plant
HESCO	Hyderabad electric supply company
QESCO	Quetta electric supply company
C02	Carbon die emission
MW	Mega Watt
ADB	Asian development bank
TOE	Tonne of oil equivalent
TWh	Tera watt hour
NREL	National renewable energy laboratory
AET's	Alternate energy technologies
VV	Variable voltage
VF	Variable frequency
VSC	Voltage source converter
IEC	International electro-technical commission
PMD	Pakistan metrological department
WT	Wind turbine
GoS	Government of Sindh
GoP	Government of Pakistan

Appendix A

Table A1. Various estimated statistics of wind zone (Sindh Province) at 10 m, 30 m and 50 m height (a) Noori Abad (b) K-Bandar (c) Jamshoro(d) Hyderabad (e) Chuhar Jamali (f) Thano Bola Khan.

Study Zones	January	February	March	April	May	June	July	August	September	October	November	December	Annual Avg
Table A1 **(a) N-Abad @ 50 m Height**													
Wind Speed (m/s)	4.9	4.8	5	7.3	9.3	10.6	10.4	9.7	8.1	4.2	4.4	4.9	7
Standard Deviation	2.9	2.8	3	3.6	4	4.7	4.3	4	3.5	2.8	2.6	2.8	4.1
Wind Power Density	160	150	179	421	773	1028	981	784	508	130	116	153	454
N-Abad @ 30 m Height													
Wind Speed (m/s)	4.2	4.3	4.4	6.6	8.6	9.7	9.5	8.8	7.5	3.7	3.7	4.2	6.2
Standard Deviation	2.6	2.5	2.7	3.4	3.8	4.5	4.1	3.8	3.3	2.5	2.2	2.5	3.9
Wind Power Density	110	105	128	319	617	859	792	634	402	89	74	104	361
N-Abad @ 10 m Height													
Wind Speed (m/s)	3	3.2	3.3	5.3	7.2	7.9	7.8	7.3	6.3	2.6	2.5	2.9	5
Standard Deviation	2.4	2.3	2.5	2.9	3.2	3.7	3.3	3	2.7	2.2	2	2.4	3.4
Wind Power Density	69	67	83	183	366	500	454	360	240	52	43	69	221
Table A1 **(b) K-Bandar @ 50 m Height**													
Wind Speed (m/s)	4.9	5.7	6.2	8.4	9.3	9.3	10.2	8.8	7.2	5.1	4.4	5	7
Standard Deviation	3	3	2.7	2.7	3.4	3.6	4.3	3	2.6	3	2.4	2.9	3.6
Wind Power Density	172	207	240	494	711	716	930	583	336	171	103	169	360
K-Bandar @ 30 m Height													
Wind Speed (m/s)	4.1	4.7	5.1	7.4	8.3	8.4	9.1	8	6.5	4.2	3.5	4.2	6.1
Standard Deviation	2.5	2.6	2.3	2.6	3.2	3.3	4.1	2.7	2.4	2.7	1.8	2.5	3.4
Wind Power Density	103	131	137	336	522	534	724	429	235	112	51	103	281
K-Bandar @ 10 m Height													
Wind Speed (m/s)	2.8	3.1	3	5.5	6.9	7.1	7.3	6.4	5	2.6	1.8	2.8	4.5
Standard Deviation	2.2	2.4	2.4	2.4	2.6	3.1	3.3	2.2	2.1	2.4	1.6	2.3	3.1
Wind Power Density	56	67	67	160	292	343	389	218	123	67	20	61	163
Table A1 **(c) Jamshoro @ 50 m Height**													
Wind Speed (m/s)	5	5.6	6.3	8.3	10.1	12.1	13.9	12.5	9.8	5.9	5.8	6.5	8.5
Standard Deviation	3.4	3.5	3.9	4.2	4.4	4.8	3.5	4	3.8	3.5	3.5	3.3	4.7
Wind Power Density	277	261	373	644	1008	1619	2102	1607	859	280	275	315	771
Jamshoro @ 30 m Height													
Wind Speed (m/s)	3.7	4.4	5	6.7	8.4	10.2	11.6	10.3	8.2	4.5	4.3	4.9	6.9
Standard Deviation	2.6	2.7	3	3.4	3.6	4.1	2.9	3.2	3.1	2.6	2.4	2.4	3.9
Wind Power Density	128	125	180	341	578	985	1246	908	499	125	106	136	423
Jamshoro @ 10 m Height													
Wind Speed (m/s)	2.4	2.5	2.7	4	5.4	6.7	7.7	6.7	5.4	2.3	1.9	2.4	4.2
Standard Deviation	1.7	1.8	1.9	2.2	2.6	2.8	2	2.1	2.3	1.7	1.3	1.6	3.1
Wind Power Density	27	29	39	81	162	284	353	243	144	26	14	24	160

Table A1. *Cont.*

Study Zones	January	February	March	April	May	June	July	August	September	October	November	December	Annual Avg
Table A1 **(d) Hyderabad @ 50 m Height**													
Wind Speed (m/s)	4.4	4.4	4.3	6.5	8.9	10	9.9	8.5	7.8	3.9	3.9	4.8	6.4
Standard Deviation	2.6	2.6	2.9	3	3.9	4	4	3	2.9	2.5	2.4	2.8	3.9
Wind Power Density	121	114	137	283	687	908	887	532	427	96	88	150	372
Hyderabad @ 30 m Height													
Wind Speed (m/s)	3.6	3.6	3.6	5.6	7.8	8.8	8.8	7.5	6.9	3.2	3.2	3.8	5.5
Standard Deviation	2.2	2.2	2.4	2.7	3.6	3.6	3.7	2.8	2.6	2.1	2	2.2	3.5
Wind Power Density	69	68	82	184	474	644	635	373	290	55	48	75	264
Hyderabad @ 10 m Height													
Wind Speed	2.2	2.3	2.1	4	5.7	6.7	6.5	5.8	5.2	1.9	1.8	1.9	3.8
Standard Deviation	1.9	1.9	2.1	2.3	2.8	2.8	2.7	2.3	2.2	1.9	1.7	1.9	2.9
Wind Power Density	35	34	46	84	202	277	265	175	134	32	25	35	123
Table A1 **(e) Chuhar Jamali @ 50 m Height**													
Wind Speed (m/s)	4.4	4.9	4.3	5.9	7.6	8	7.9	7.5	6.5	3.9	4.1	4.7	5.8
Standard Deviation	2.9	2.8	3.3	3.5	3.3	3.4	3.5	3.1	3.3	2.8	2.8	2.7	3.5
Wind Power Density	144	158	176	285	432	504	450	404	310	113	118	139	276
Chuhar Jamali @ 30 m Height													
Wind Speed (m/s)	3.9	4	3.6	5.1	6.6	7.1	6.9	6.4	5.3	3.1	3.3	3.9	5
Standard Deviation	2.4	2.4	2.8	3	2.9	3.2	3.1	2.9	2.6	2.3	2.3	2.3	3
Wind Power Density	88	92	116	185	290	353	329	266	160	65	67	85	177
Chuhar Jamali @ 10 m Height													
Wind Speed (m/s)	2.8	2.6	2.6	3.9	5.1	5.5	5.3	4.5	3	1.6	1.7	2.4	3.4
Standard Deviation	3	2.8	2.8	3.2	3.1	3.4	3.2	3.7	3.1	2.4	2.3	2.7	3.2
Wind Power Density	153	114	115	160	186	240	211	266	156	103	84	100	168
Table A1 **(f) TB-Khan @ 50 m Height**													
Wind Speed (m/s)	3.3	3.6	2.6	5.3	6.8	8.6	8.5	7.6	6.8	2.3	2.4	3.3	5.1
Standard Deviation	2.8	3	3.3	4	4.7	4.3	4.4	3.8	3.6	2.7	2.5	3	4.2
Wind Power Density	118	134	233	323	571	683	705	502	376	118	87	127	374
TB-Khan @ 30 m Height													
Wind Speed (m/s)	2.6	3	2.1	4.4	5.8	7.4	7.4	6.5	5.7	1.8	1.8	2.7	4.3
Standard Deviation	2.4	2.6	2.7	3.4	4.1	3.8	4	3.4	3.1	2.2	2.1	2.5	3.7
Wind Power Density	65	82	125	196	375	460	486	319	227	62	47	75	243
TB-Khan @ 10 m Height													
Wind Speed	1.6	1.9	1.4	2.8	4.4	5.4	5.7	4.9	3.8	1	1.1	1.6	3
Standard Deviation	1.9	2	2	2.6	3.1	2.9	3.1	2.6	2.5	1.6	1.6	2	2.9
Wind Power Density	39	40	55	85	162	189	231	138	95	32	30	49	117

Table A2. Various estimated statistics of wind zone (Baluchistan Province) at 10 m, 30 m and 50 m height (a) Gadani (b) Jiwani(c) Hubchoki (d) Aghore (e) Winder and (f) Gwadar.

Study Zones	January	February	March	April	May	June	July	August	September	October	November	December	Annual Avg
Table A2 **(a) Gadani @ 50 m Height**													
Wind Speed (m/s)	4.5	4.7	4.9	6.3	8.2	8.5	8.6	7.7	6.6	3.9	3.8	4.7	6.0
Standard Deviation	2.9	2.9	2.6	2.9	3.1	3.7	3.7	2.9	2.7	2.8	2.7	2.8	3.5
Wind Power Density	144.9	148.1	138.3	249.9	498.6	593.8	612.1	417.7	269.6	118.1	103.7	146.6	287.8
Gadani @ 30 m Height													
Wind Speed (m/s)	3.3	3.5	3.8	5.2	7.0	7.2	7.2	6.6	5.6	2.9	2.7	3.4	4.9
Standard Deviation	2.1	2.2	2.1	2.5	2.9	3.3	3.3	2.7	2.4	2.1	1.9	2.1	3.0
Wind Power Density	58.6	68.5	69.7	148.7	320.2	380.1	380.9	267.3	169.8	51.6	39.1	59.5	170.5
Gadani @ 10 m Height													
Wind Speed (m/s)	0.9	1.1	1.5	1.3	4.9	5.0	4.8	4.6	3.7	0.8	0.5	0.9	2.7
Standard Deviation	1.4	1.7	1.9	2.5	2.5	2.6	2.5	2.3	2.3	1.4	1	1.4	2.6
Wind Power Density	17.2	29.7	39.6	75.8	132.1	139.7	131.3	106.7	76.6	18.8	6.6	19.0	86.2
Table A2 **(b) Jiwani @ 50 m Height**													
Wind Speed (m/s)	3.8	4	4.4	5.5	5.3	4.8	4.6	4.3	3.9	3.7	4.2	4.4	4.4
Standard Deviation	2.4	2.5	2.5	2.9	2.7	2.7	2.6	2.5	2.6	2.3	2.3	2.9	2.6
Wind Power Density	82.1	93.7	114.6	194.6	163.5	140.6	125.7	106.7	110.4	81.4	78.2	136.1	119
Jiwani @ 30 m Height													
Wind Speed (m/s)	3	3.3	3.7	4.6	4.5	4.3	4	3.8	3.7	3.2	3	3.4	3.7
Standard Deviation	2	2.1	2.2	2.6	2.5	2.5	2.4	2.3	2.4	2	1.9	2.5	2.4
Wind Power Density	45	56.3	70.3	126.4	115.9	104.2	92.9	78.5	78.4	47.1	42	79.5	78.4
Jiwani @ 10 m Height													
Wind Speed (m/s)	1.7	2	2.3	3.1	3.3	3.3	3.1	2.9	2.7	2	1.6	1.9	2.5
Standard Deviation	1.5	1.8	1.9	2.3	2.3	2.2	2.1	2	2.1	1.7	1.5	1.9	2
Wind Power Density	15.8	26.6	33.2	63.2	65.3	61.3	54.5	45.5	45.8	24.6	16.3	31.1	41.9
Table A2 **(c) Hubchoki @ 50 m Height**													
Wind Speed (m/s)	4.0	4.6	5.3	6.5	7.4	7.7	9.0	8.1	6.6	4.2	3.6	3.8	5.9
Standard Deviation	2.4	2.4	2.4	2.5	2.4	2.8	3.0	2.7	2.5	2.5	2.1	2.4	3.1
Wind Power Density	89.7	114.0	151.9	251.0	346.4	404.5	620.3	447.6	8257.8	103.9	65.2	83.6	240.5
Hubchoki @ 30 m Height													
Wind Speed (m/s)	3.3	3.9	4.5	5.6	6.5	6.8	7.4	6.6	5.5	3.5	2.9	3.1	5.0
Standard Deviation	2.0	2.1	2.1	2.3	2.2	2.5	1.7	2.0	1.9	2.2	1.7	2.0	2.6
Wind Power Density	53.3	68.3	91.8	159.2	229.5	276.9	312.9	229.1	141.1	63.1	33.7	45.0	139.1
Hubchoki @ 10 m Height													
Wind Speed (m/s)	2.2	2.5	2.9	3.9	4.8	5.2	5.0	3.7	3.6	2.3	1.7	1.7	3.3
Standard Deviation	1.7	1.8	1.9	2.1	2.0	2.1	3.4	2.5	2.2	1.8	1.6	1.5	2.4
Wind Power Density	25.6	31.3	40.8	70.5	105.1	128.0	215.8	87.3	70.5	29.7	20.1	15.6	72.6

Table A2. *Cont.*

Study Zones	January	February	March	April	May	June	July	August	September	October	November	December	Annual Avg
Table A2 **(d) Aghore @ 50 m Height**													
Wind Speed (m/s)	5.1	5.1	5.2	6.4	7.9	8.3	8.2	7.9	6.2	4.6	4.7	5.3	6.2
Standard Deviation	1.6	1.8	1.9	2.1	2.5	2.5	2.4	2.1	2.1	1.7	1.3	1.6	2.6
Wind Power Density	128.2	127.7	134.5	231.2	432.5	509.3	479.4	420.4	221.1	112.5	106.3	140.2	247.3
Aghore @ 30 m Height													
Wind Speed (m/s)	4.1	4.2	4.5	5.8	7.2	7.6	7.4	7.2	5.7	3.8	3.7	4.2	5.5
Standard Deviation	1.8	1.9	1.9	2.2	2.7	2.9	2.8	2.4	2.2	2.0	1.6	1.7	2.7
Wind Power Density	66.4	73.7	87.1	168.8	334.5	388.5	364.8	315.7	165.0	64.3	50.0	69.4	173.5
Aghore @ 10 m Height													
Wind Speed	2.6	2.9	3.3	4.8	6.3	6.5	6.3	6.1	4.8	2.6	2.2	2.6	4.2
Standard Deviation	2.4	2.5	2.6	2.9	2.7	2.4	2.3	2.1	2.2	2.4	2.2	2.4	2.7
Wind Power Density	24.3	35.2	48.0	106.6	228.8	247.6	220.9	194.0	106.2	27.6	14.9	24.3	108.2
Table A2 **(e) Winder @ 50 m Height**													
Wind Speed (m/s)	4.0	4.4	5.4	6.4	7.1	6.9	7.1	6.2	5.6	3.7	3.2	4.0	5.3
Standard Deviation	2.9	2.9	3.2	3.2	3.0	2.7	2.7	2.3	2.4	3.0	2.7	3.0	3.2
Wind Power Density	132.4	142.3	213.1	297.6	346.4	304.7	331.8	218.6	167.4	130.4	100.2	137.4	208.6
Winder @ 30 m Height													
Wind Speed (m/s)	3.6	4.0	4.9	6.0	6.5	6.4	6.5	5.8	5.1	3.3	2.8	3.5	4.9
Standard Deviation	2.6	2.7	3.0	3.0	2.8	2.6	2.6	2.1	2.2	2.7	2.4	2.7	9
Wind Power Density	95.7	107.7	161.1	237.3	269.2	246.1	258.3	172.1	127.4	93.6	66.2	98.8	160.7
Winder @ 10 m Height													
Wind Speed (m/s)	2.9	3.3	4.1	5.3	5.7	5.7	5.7	5.1	4.3	2.6	2.1	2.7	4.1
Standard Deviation	2.4	2.5	2.6	2.9	2.7	2.4	2.3	2.1	2.2	2.4	2.2	2.4	2.7
Wind Power Density	68.7	77.3	105.1	179.1	194.6	180.5	172.7	126.9	91.8	64.1	55.8	68.3	116.6
Table A2 **(f) Gwadar @ 50 m Height**													
Wind Speed (m/s)	3.7	4.2	4.4	5.1	4.4	4.6	4.5	4	3.9	3.7	3.4	4	4.2
Standard Deviation	2.5	2.9	3.1	3.3	2.8	2.7	2.5	2.2	2.3	2.5	2.5	3.2	2.8
Wind Power Density	87.7	135.9	157.9	218.1	132.1	132	116.1	83.2	83.2	87.6	81.8	162.1	121.4
Gwadar @ 30 m Height													
Wind Speed (m/s)	3	3.4	3.6	4.4	3.8	4.1	4.1	3.6	3.4	3.1	2.8	3.3	3.6
Standard Deviation	1.9	2.4	2.6	3	2.6	2.5	2.4	2.1	2.2	2.3	2.1	2.7	2.5
Wind Power Density	40.6	75.2	91.6	146.3	97.5	101.8	90	63.2	61.7	59.3	49.3	91.9	80.4
Gwadar @ 10 m Height													
Wind Speed	2	2.4	2.5	3.2	2.9	3.3	3.4	2.9	2.6	2.1	1.9	2.2	2.6
Standard Deviation	1.5	2	2.2	2.6	2.3	2.3	2.1	1.9	2	2	1.7	1.9	2.1
Wind Power Density	18.4	41.7	51.7	84.8	58.6	64.3	56	39.5	38.8	39.9	25.4	35.4	46.5

Table A3. Various wind energy projects [25,77–83].

Project City/Province	Name of Company	Installation Capacity [MW]	Project Status
Jhimpir/Sindh	Zephyr Power Ltd.	50	Under construction, to be completed by December 2016
	Yunus Energy Limited	50	6 MW Operational since 2009; 50.4 MW added in March 2013
	Wind Eagle (Pvt) Limited	50	Operational since December2012
	UEPL Wind Power Pakistan (Pvt) Ltd.	100	Under construction
	Trident Energy (Pvt) Ltd.	50	Under construction
	Tricon Boston Corporation	50	Under construction
	Titan Energy Pakistan (Pvt) Ltd.	50	Under construction, to be completed by December 2016
	Three Gorges First Wind Farm Pakistan Ltd.	49.5	Under construction
	Sachal Engineering Works (Pvt) Limited	50	Under construction
	Metro Wind Power Co., Limited	50	Under construction
	Master Wind Energy Limited	49.5	Under construction, to be completed by December 2016
	Jhimpir Wind Power Plant	56.4	6 MW Operational since 2009; 50.4 MW added in March 2013
	Jhimpir Wind Energy Project (FFCEL)	49.6	Operational since December 2012
	Hawa Energy Ltd.	50	Under construction
	Hartford Alternate Energy	50	Under construction
	Gul Ahmed Wind Power Limited	50	Under construction, to be completed by December 2016
	Finerji (Pvt) Ltd.	50	Under construction
	Dewan Energy (Pvt) Ltd.	50	Under construction
	China Sunec Energy Pvt Ltd.	50	Under construction
Bhambore/Sindh	Zephyr Power Ltd.	50	Under construction, to be completed by December 2016
	Hydro China Dawood Power Ltd.	50	Under construction
Bhambore/Gharo Sindh	Dawood Power (Pvt) Limited	50	
Thatta/Sindh	Thatta Power Plant	150	Operational since January 2015
Khutti Kun, Mirpur Sakro/ Sindh	TenagaGenerai Limited	49.5	Under construction
Khutti Kun, Gharo	Foundation Wind Energy–I & II Pvt. Ltd.	100	Operational since January 2015
Gharo/Sindh	Bhambore Wind Project	50	Under construction
Thatta/Sindh	Sapphire Wind Power (Pvt) Limited	49.5	Under construction wind energy project
Karachi/Sindh	Mbm Engineering Company	1	Letter of intent
Gharo/Sindh	Gharo Wind Power Plant	50	Under construction
Punjab	AM Pak Energy	50	Letter of intent
Baluchistan	***No any***	***0***	***No any***

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